

## **A Review of the Haspert Model for Target Identification**

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## ABSTRACT

The Haspert model for target identification using multiple sensors is examined. Haspert takes a total-cost approach in constructing identification rules for engagements in which friendly, hostile and neutral parties are involved. While the model has certain advantages in terms of command and scenario flexibility, the resulting identification rules vary considerably according to the cost parameters set by commanders, and in some cases are counterintuitive. The model does not offer significant advantages in the identification of neutrals unless information on the nature and number of these parties is available prior to the engagement.

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# A Review of the Haspert Model for Target Identification

## Executive Summary

Identification of military combatants is problematic in many engagement scenarios. An individual sensor will never be completely accurate in identifying hostile, friendly and neutral combatants. If more than one sensor is employed the resulting identifications may conflict.

This paper examines Haspert's framework for combining output from multiple sensors when making target identifications. A cost is assigned to the misidentification of friendly, hostile and neutral combatants. A rule for declaring targets hostile which minimises the expected total misidentification cost is then determined.

Haspert's approach can accommodate identification problems with arbitrary numbers of sensors and target types. Considerable flexibility exists within the model which could be of benefit in changing combat scenarios. However, there are also a number of potential weak points in the model. Foremost of these, is the problem of assigning cost parameters. There may be wide variation in the values chosen by commanders in a given engagement context, which could result in significant variation in the number of targets declared hostile. In addition, the hostile declaration rules determined are in many cases counterintuitive and could be disregarded if they conflicted with the individual judgement of military commanders.

Most of the analysis in this paper examines hostile declaration rules determined in engagements where only hostile and friendly combatants are considered. The model does not offer significant advantages in the identification of neutrals unless the number and type of these parties is known prior to an engagement.

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## 1. Introduction

Target identification using multiple sensors remains an unresolved issue for military combatants. In this paper a model for target identification, called here the Haspert model, is examined. Haspert[1] takes a total cost approach which extends the work of Ralston[2] on this topic.

Any individual sensor is an imperfect instrument for making target identifications. If more than one sensor is used in an engagement the resulting identifications may conflict. Careful analysis is therefore required to combine or fuse the data from a number of different sensors.

In [2], Ralston assigns theoretical costs to the misidentification of individual hostile and friendly combatants in an engagement. The optimal hostile declaration rule can then be determined by selecting the set of sensor output combinations which results in the expected minimum total cost. This is computationally straightforward when only hostile and friendly targets are being considered, but is far more problematic when more than two target types are involved.

Many modern military engagements involve not only friendly and hostile combatants but also neutral parties, so target identification rules need to allow for this possibility. The Haspert model provides a simple method of determining whether a given sensor output combination should be included in a hostile declaration rule for an arbitrary number of target types.

The model has a number of advantages in terms of command flexibility, as it allows cost parameters to be varied at any time during an engagement, according to the particular military objectives and combat environment. However, some of the hostile declaration rules resulting from the model appear counterintuitive and might be disregarded by commanders when they conflict with their personal judgement.

The Haspert model also assumes that reliable information is available on the nature and number of hostile, friendly and neutral parties involved in an engagement, and the degree of sensor reliability in identifying each. In many combat situations, information relating to neutral parties is often far from complete. Hence, in practice the Haspert model may be of limited benefit in identifying neutrals.

## 2. The Haspert model

While the Haspert model was formulated for the optimal identification of hostile, friendly and neutral combatants, this paper will first deal with the two target type (i.e. friendly & hostile) problem.

First it will be necessary to define a sensor profile. For a sensor operating in two-target type engagement, a sensor may indicate a friend (F), hostile (H) or may give an unknown indication (U). A sensor profile is a matrix of probabilities which reflect how reliable a sensor is in making target identifications.

*Table 1 Generalised example of a sensor profile for the two-target type problem*

Actual target type	Sensor indications		
	Friend (F)	Hostile (H)	Unknown(U)
true Friend	$P_*(F tF)$	$P_*(H tF)$	$P_*(U tF)$
true Hostile	$P_*(F tH)$	$P_*(H tH)$	$P_*(U tH)$

In Table 1,  $P_*(H|tF)$  for example, represents the probability that the sensor will indicate a hostile (H) when the target is in reality a friend (tF).

To gain a better understanding of how the model would work in practice, it should be assumed that the sensors employed have some minimal level of accuracy. Therefore, none of the sensor profiles being examined will be less than 70% accurate; that is, the entries in the sensor profiles  $P_*(H|tH)$  and  $P_*(F|tF)$  are at least 0.7.

The Haspert target declaration model takes two sensor profiles and creates a sequence of sensor output vectors, based on the possible combinations of outputs. There are a total of nine ( $=3^2$ ) possible sensor output vectors for each pair of sensors. These are labelled alphabetically in Table 2.

*Table 2 The set of sensor output vectors for the two target-type (friendly-hostile) problem*

Vector label	Sensor A output	Sensor B output
a	Friend	Friend
b	Friend	Hostile
c	Friend	Unknown
d	Hostile	Friend
e	Hostile	Hostile
f	Hostile	Unknown
g	Unknown	Friend
h	Unknown	Hostile
i	Unknown	Unknown

The problem is to determine which set of sensor output vectors should be included in the hostile declaration rule. If a target presents with a sensor output vector in the hostile declaration rule then it will be declared hostile.

The purpose of constructing a hostile declaration rule is to determine which targets should be identified as hostile, rather than to classify all targets as either friendly or

hostile. Haspert [1] outlines how the minimum cost approach can be modified to produce optimal declaration rules for identification of friendly targets, although this is not the main interest of this paper.

The probability functions represented in sensor profiles A and B shall be denoted  $P_A$  and  $P_B$  respectively. The function which gives the combined probability of each sensor output vector will be denoted as  $P$ . If we wish to refer to the probability function of a general individual sensor we shall use the notation  $P^*$ .

Now if it is assumed that the two sensors are statistically independent, each output vector can be assigned a point in the two dimensional co-ordinate plane by

$$\begin{aligned} x &= P(\text{output} | tF) = P_A(\text{output}_A | tF) \cdot P_B(\text{output}_B | tF) \\ y &= P(\text{output} | tH) = P_A(\text{output}_A | tH) \cdot P_B(\text{output}_B | tH), \end{aligned}$$

where *output* is the pair of indications (*output<sub>A</sub>*, *output<sub>B</sub>*) which defines each sensor output vector.

So for example, for output vector **b**, *output<sub>A</sub>*=Friend, *output<sub>B</sub>*=Hostile and

$$\begin{aligned} x &= P_A(\text{Friend} | tF) \cdot P_B(\text{Hostile} | tF) \\ y &= P_A(\text{Friend} | tH) \cdot P_B(\text{Hostile} | tH). \end{aligned}$$

Note that the assumption of statistical independence of the sensor outputs is not an integral part of the model as a whole. If required, correlation of the sensor outputs could easily be accommodated.

A combination of two perfectly accurate sensors would have output vector **e** with *x-y* co-ordinates (0,1). This vector could be used on its own as an ideal rule for target identification. Using this rule, a hostile declaration would only be made if both sensors indicated a target to be hostile. As the *y* co-ordinate of **e** would be 1 this would imply that all true hostiles would be identified as hostiles. The *x* co-ordinate of 0 would mean that no friend would ever be declared to be hostile.

Of course, in practice no sensor is ever 100% accurate. Hence, there will only be sensor output vectors close to (0,1) in the *x-y* plane available for inclusion in any hostile declaration rule. The question that arises naturally is "How close does it have to be?"

Haspert answers this question by plotting a total cost line in the *x-y* plane, and then determining which sensor output vectors point towards this line.

The total cost ( $C_T$ ) is defined as

$$C_T = C_{PL} \times P_H \times p(\text{hostile not declared hostile}) + C_F \times P_F \times p(\text{friend declared hostile}), \quad (1)$$

where

$C_{pL}$  is the cost of a hostile not declared hostile (i.e. the cost of a "potential leaker");

$C_F$  is the cost of identifying a friend as hostile;

$P_H$  is the probability that a yet-to-be identified target is hostile ( $P_H$  is proportional to the number of hostiles  $N_H$ );

$P_F$  is the probability that a yet-to-be identified target is friendly ( $P_F$  is proportional to the number of friends  $N_F$ );

$p(\text{hostile not declared hostile})=1-p(\text{hostile declared hostile})=1-P(\text{output} | tH)$ ; and

$p(\text{friend declared hostile})=P(\text{output} | tF)$ .

If a friendly declaration rule was to be formulated, then the cost parameters and probabilities used in the total cost expression would relate to a friend not being identified as a friend and a hostile being identified as a friend.

By using variables  $x = P(\text{output} | tF)$  and  $y = P(\text{output} | tH)$  and fixing a total cost, equation (1) can be rearranged to produce the following formula:

$$y = \left( \frac{C_F N_F}{C_{pL} N_H} \right) x + \left( \frac{C_{pL} N_H - C_T}{C_{pL} N_H} \right). \quad (2)$$

For minimum total cost ( $C_T = 0$ ) this reduces to  $y = \left( \frac{C_F N_F}{C_{pL} N_H} \right) x + 1$ .

All the cost lines have a normal vector

$$N = \begin{pmatrix} C_F N_F \\ -C_{pL} N_H \end{pmatrix}.$$

The dot product<sup>1</sup> of  $N$  and any vector which points towards the minimum cost line will be less than or equal to zero. In the Haspert model, hostile declaration rules are formulated according to the following principle:

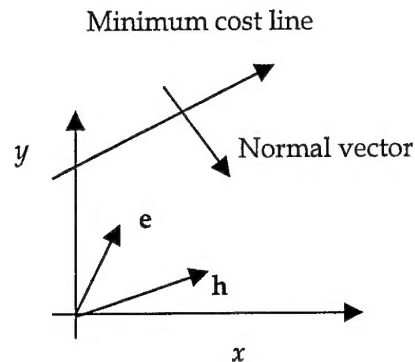
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<sup>1</sup> The dot product of two vectors  $\mathbf{v}_1 = \begin{pmatrix} v_1^1 \\ v_1^2 \end{pmatrix}$  and  $\mathbf{v}_2 = \begin{pmatrix} v_2^1 \\ v_2^2 \end{pmatrix}$  is defined as

$$\mathbf{v}_1 \bullet \mathbf{v}_2 = v_1^1 v_2^1 + v_1^2 v_2^2.$$

*If a sensor output vector and a normal vector to the minimum cost line have a non-positive dot product, the sensor output vector will be included in the hostile declaration rule.*

This is illustrated by the following diagram.



*Figure 1 Determining the sensor output vectors to be included in the hostile declaration rule.*

In Figure 1 for the particular values of the parameters  $C_F$ ,  $N_F$ ,  $C_H$  and  $N_H$ , the sensor output vector  $e$  (Sensor A and Sensor B both identify as hostile) which points towards the minimum cost line as  $e \cdot N < 0$  would be included in the hostile declaration rule. Vector  $h$  (Sensor A identifies as unknown, Sensor B identifies as hostile) would not be included as  $h \cdot N > 0$ .

To simplify the analysis of the model the four parameters  $C_F$ ,  $C_{pL}$ ,  $N_F$ ,  $N_H$  will be incorporated into one number which will be known as the aggression factor. The aggression factor is the ratio

$$\frac{C_{pL} N_H}{C_F N_F}.$$

Note that this number is the inverse of the slope of the total cost lines.

The aggression factor represents the total cost of identifying all hostiles as friends, compared to the total cost of identifying all friends as hostiles. Increasing the aggression factor will increase the likelihood that a given target will be declared hostile.

It should be stressed that the fact that a target is declared hostile does not necessarily imply that it will be engaged let alone destroyed, and in setting the cost factors this should be taken into consideration.

Other points which should be taken into account when setting the cost factors would be

- if a friend is declared hostile then time and resources may be expended engaging this friend, while true hostiles are not engaged;
- the psychological effects of fratricide on combat personnel could be significant, depending on the engagement;
- the ratio  $C_{pl}/C_F$  will vary significantly with the engagement. Consider an FFG protecting HVUs, being attacked and defended by fighter-bomber aircraft. In this context, the cost of an allied aircraft being destroyed through misidentification might be small compared to the damage which could be effected by a hostile aircraft which was declared friendly.

Given an increased aggression factor, more sensor output vectors will be included in the hostile declaration rule and hence combatants would be more ready to engage targets, as would be expected. However the Haspert model can produce hostile declaration rules which appear to be somewhat counterintuitive. Depending on the method of implementation, this could potentially be a major drawback of the model as the resulting identifications may conflict with the judgement of commanders. This will be discussed further in later sections.

The other area of concern with the implementation of the Haspert model would be the choice either of parameters  $C_F$  and  $C_{pl}$  ( $N_F$  and  $N_H$  could presumably be fairly objectively determined in an engagement involving only hostile and friendly combatants) or more simply, the aggression factor. The ability to vary these values is both a strong point of the model, as it allows for greater flexibility in decision making, and a potential weakness. While certain engagements would have a fairly canonical range of values for these variables, in some situations there could be wide disagreement in the perceived appropriate values for these parameters.

At a more fundamental level, the Haspert model requires that the level of sensor reliability can be fixed at any point in time during an engagement. While this would be a reasonable assumption to make in a number of combat contexts, it is well known, for example, that radar detections of targets over land are more problematic than those made of targets over open ocean. So in a littoral engagement, one radar could have two significantly different sensor profiles. Whether such examples could be accommodated by extensions of the Haspert model remains an open question.

### 3. Symmetric Sensor Profiles

The four sensor combinations given in Tables 3-6 have been chosen to demonstrate some of the decision features of the Haspert model. If the accuracy of the component sensors is compared, then Profile 2 is the most accurate overall. Profile 4 is the least accurate, with Profiles 1 and 3 lying somewhere in between. Profiles 1-4 have been deliberately constructed so that in each case sensor A is less accurate than sensor B.

In addition, each of the following profiles in this section is symmetric. That is,

$$P_*(H | tH) = P_*(F | tF),$$

$$P_*(H | tF) = P_*(F | tH)$$

and

$$P_*(U | tH) = P_*(U | tF).$$

Of course, this sort of sensor profile is extremely artificial, but initially the above properties will significantly simplify the analysis required.

*Table 3 Sensor combination Profile 1*

Profile 1	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.8	0.1	0.1
	tH	0.1	0.8	0.1
		F-B	H-B	U-B
Sensor B	tF	0.95	0.03	0.02
	tH	0.03	0.95	0.02

*Table 4 Sensor combination Profile 2*

Profile 2	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.9	0.05	0.05
	tH	0.05	0.9	0.05
		F-B	H-B	U-B
Sensor B	tF	0.95	0.03	0.02
	tH	0.03	0.95	0.02

Table 5 Sensor combination Profile 3

Profile 3	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.75	0.2	0.05
	tH	0.2	0.75	0.05
		F-B	H-B	U-B
Sensor B	tF	0.95	0.03	0.02
	tH	0.03	0.95	0.02

Table 6 Sensor combination Profile 4

Profile 4	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.75	0.2	0.05
	tH	0.2	0.75	0.05
		F-B	H-B	U-B
Sensor B	tF	0.8	0.15	0.05
	tH	0.15	0.8	0.05

To give a measure of a sensor's accuracy the profile determinant  $D$  is defined by

$$D = P \cdot (H | tH) + P \cdot (F | tF) - P \cdot (H | tF) - P \cdot (F | tH)$$

For example in Profile 4 sensor A has

$$D(A) = 0.75 + 0.75 - 0.2 - 0.2 = 1.1.$$

This is of course, a very arbitrary way of measuring reliability. In fact the definition could perhaps be improved by varying the negative weightings on  $P \cdot (F | tH)$  and  $P \cdot (H | tF)$ . This question will be discussed further in Section 4.

The perfectly accurate sensor would have a profile determinant of 2. For a pair of sensors a combination determinant can be introduced:

$$D(A,B) = D(A) + D(B).$$

Using the combination determinants as a measure of accuracy, the profiles can be ranked in decreasing order of reliability.

Profile 2 > Profile 1 > Profile 3 > Profile 4.

Hence Profile 2 represents the most reliable sensor combination and Profile 4 the least.

Now the different hostile declaration rules which result from the Haspert model will be compared. For any sensor combination, as the aggression factor is increased the number of sensor output vectors included in the hostile declaration rule also increases. The order in which this occurs will be known as a *declaration ordering*. Profiles 1-4 all have the same declaration ordering given in Table 7.

Table 7 Declaration ordering for Profiles 1-4

Increasing aggression factor →									
Output vectors	e	h	f	b	i	d	c	g	a
Sensor outputs	A-H B-H	A-U B-H	A-H B-U	A-F B-H	A-U B-U	A-H B-F	A-F B-U	A-U B-F	A-F B-F

Note that as will be shown later, this ordering of sensor output vectors may be different if the original sensor profiles are asymmetric, or if  $P(U|tH) > P(F|tH)$  or  $P(U|tF) > P(H|tF)$ .

For an aggression factor close to zero, no hostile declarations may be made, depending on the accuracy of the sensors being used. As the aggression factor increases, a combatant will first be declared hostile if both sensors identify it as hostile (vector e). Then, as the aggression factor becomes larger a combatant will also be declared hostile if sensor B identifies it as hostile and sensor A has an unknown indication output (vector h), and so on.

In the 2-combatant type problem, the declaration orderings are obtained by ranking the sensor output vectors according to the ratio

$$\frac{P(\mathbf{x}|tH)}{P(\mathbf{x}|tF)}.$$

If this ratio is greater than or equal to the slope of the cost line (i.e.  $\frac{C_F N_F}{C_{pL} N_H}$  or the inverse of the aggression factor) then the sensor output vector  $\mathbf{x}$  will be included in the hostile declaration rule.

The increase in number of sensor output vectors included in the hostile identification rule for aggression factors greater than or equal to 1 is represented in Figure 2.

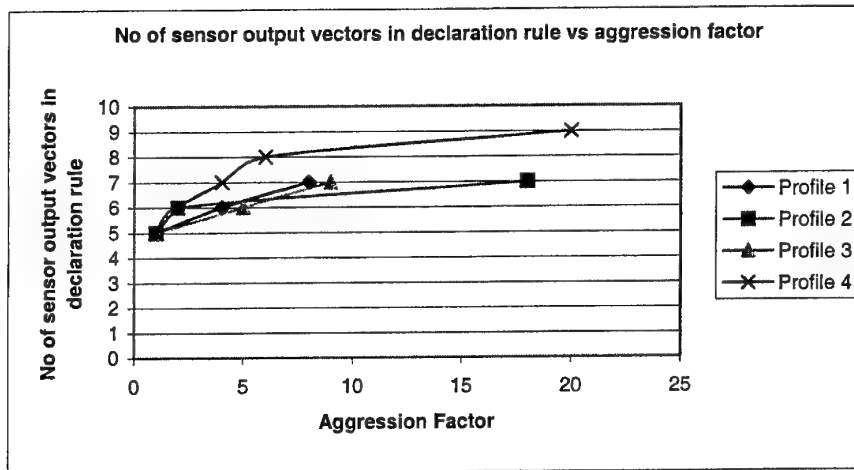


Figure 2 Number of sensor output vectors in hostile identification rule vs aggression factor for Profiles 1-4

The points for which all nine vectors are included in the hostile declaration rule have not been shown in Figure 2 other than for Profile 4. To declare a combatant hostile when both sensors indicate a friend would be effectively taking a shoot-if -it-moves approach to the engagement.

For an aggression factor of one, using any of the four sensor combinations a hostile declaration would be made for sensor output vectors **e**, **h**, **f**, **b** and **i**. Note that although Profile 4 represents the least accurate sensor combination, the graph shows that for an aggression factor of 2, the least and the most accurate sensor combinations would use the same rules in making hostile declarations (**e**, **h**, **f**, **b**, **i** and **d**). Profiles 3 and 1 represent a mid range of sensor accuracy, however using these profiles and an aggression factor of 2 combatants would be less ready to declare a target hostile as the hostile declaration rule at this aggression factor would not contain vector **d**.

### 3.1 Discussion

That a less accurate sensor combination will more readily make hostile declarations at a given aggression factor can be explained using a "fuzzy logic" approach to target identification. Such an approach might begin with a principle such as:

*GOOD TIMES RULE(GTR) –The less sure I am of my sensors, the less ready I should be to declare someone my enemy.*

Of course, such a principle on its own would not take full account of the fact that less accurate sensors not only identify friends as hostiles, but hostiles as friends. In terms of the Haspert model, this would be equivalent to underestimating the parameter  $C_p$

The more paranoid version of the above principle, which also makes sense depending on the context is of course:

*BAD TIMES RULE(BTR) –The less sure I am of my sensors, the less ready I should be to regard someone as my friend.*

A rough idea of target declaration rules based on the above principles would be to use the GTR only when the aggression factor is low. As the aggression factor increases, the BTR would gradually be regarded as more important.

If the Haspert model is examined in the light of this framework, and if Good Times are regarded as being situations in which the aggression factor is less than 1, then it appears that the resulting declaration rules accord with the GTR.

*Table 8 Minimum aggression factors for each number of sensor output vectors in declaration rule for Profiles 1-4 and Aggression factors <1*

No of output vectors in declaration rule	Approximate minimum aggression factor for no. of sensor output vectors			
	Profile 1	Profile 2	Profile 3	Profile 4
1	0.01	0.01	0.01	0.05
2	0.1	0.05	0.1	0.2
3	0.2	0.1	0.2	0.3
4	0.3	0.6	0.3	0.75

It can be seen from Table 8 that Profile 2 makes the first three declarations by aggression factor 0.1, while at that value, Profile 4 has only been able to make 1 hostile declaration.

Examining compliance with the BTR (i.e. the figures for aggression factor  $\geq 1$ ) the following numbers are obtained.

*Table 9 Minimum aggression factors for each number of sensor output vectors in declaration rule for Profiles 1-4 and Aggression factors  $\geq 1$ .*

No of output vectors in declaration rule	Approximate minimum aggression factor for no. of sensor output vectors			
	Profile 1	Profile 2	Profile 3	Profile 4
5	1	1	1	1
6	4	2	5	2
7	8	18	9	4
8	32	32	32	6
9	254	570	119	20

The above results appear to be in compliance with the BTR. The least accurate sensor combination represented by Profile 4 is the quickest to make hostile declarations as the

aggression factor increases. The last sensor combination to take a shoot-if-it-moves approach is Profile 2, the most accurate sensor combination.

So the Haspert model is in fact consistent with the fuzzy logic framework outlined above. A generalised comparison of declaration profiles for two sensor combinations with the same declaration ordering is given in Figure 3.

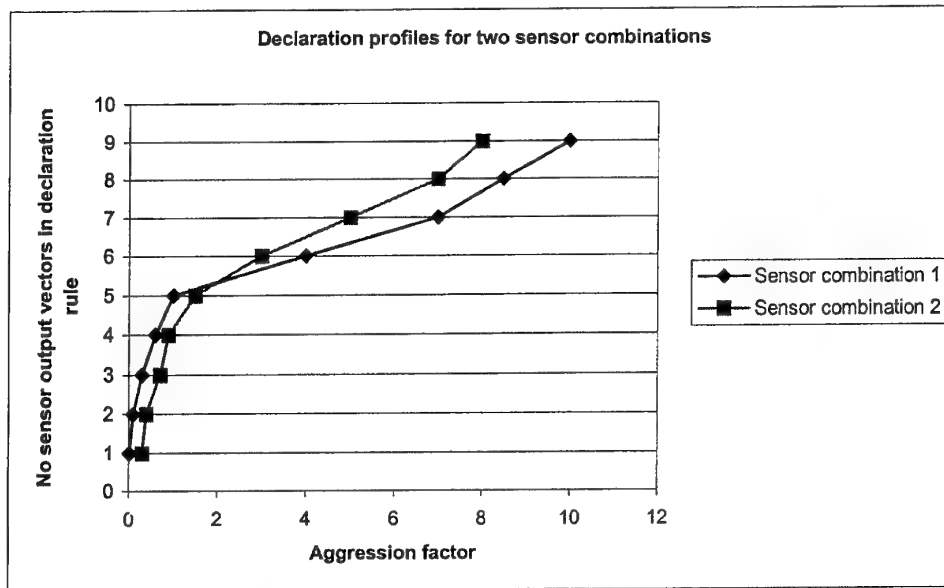


Figure 3 Generalised comparison of hostile identification rules for two profiles with the same declaration ordering

In the above diagram, Sensor combination 1 (SC1) is more accurate than Sensor combination 2 (SC2). At lower aggression factors greater confidence in the output from SC1 would result in more hostile declarations than would be made using SC2. However, as the aggression factor increases, combatants would be more likely to be declared hostile using SC2. This is due to the fact that the individual sensors in SC2 are less reliable, and are more likely to identify a true hostile as a friend.

### 3.2 Accuracy issues

Another rule which might be included in a fuzzy logic target identification framework is the following:

*ACCURACY RULE- If I have a direct conflict between two sensors, I will believe the more accurate sensor.*

The Haspert model might appear to contradict this principle. Consider the example given in Table 10.

Table 10 Sensor combination Profile 5

Profile 5	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.75	0.1	0.15
	tH	0.1	0.75	0.15
		F-B	H-B	U-B
Sensor B	tF	0.87	0.12	0.01
	tH	0.12	0.87	0.01

If the profile determinants of the two sensors ( $D(A) = 1.3$ ,  $D(B)=1.5$ ) are compared, then it might be assumed that sensor B is more reliable in making hostile declarations. Of course while sensor B is more likely to identify true hostiles and friends correctly, it is also slightly more likely to make false friend and hostile identifications. Sensor A on the other hand, will be much more likely to give unknown indications.

The declaration ordering for Profile 5 is given in Table 11.

Table 11 Declaration ordering for Profile 5

Increasing aggression factor →									
Output vectors	e	f	h	d	i	b	g	c	a
Sensor outputs	A-H	A-H	A-U	A-H	A-U	A-F	A-U	A-F	A-F
	B-H	B-U	B-H	B-F	B-U	B-H	B-F	B-U	B-F

Note that for this sensor combination, as the accuracy of sensor B (as measured by the profile determinant) is higher than that of sensor A, a target presenting with output vector **d** than would more readily declared hostile than a target with output vector **b**. Remember that sensor B is significantly better at identifying true hostiles as hostile, but using the Haspert model, sensor A is more likely to be "believed" in making hostile declarations.

Again, this can be explained by noting that

$$\frac{P(d|tH)}{P(d|tF)} = \frac{0.75 \times 0.12}{0.10 \times 0.87} > \frac{P(b|tH)}{P(b|tF)} = \frac{0.10 \times 0.87}{0.75 \times 0.12}.$$

The fact that hostile declaration ordering varies from that seen in the previous section is due to the fact that for sensor A,

$$P_A(\text{Unknown} | tF) > P_A(\text{Hostile} | tF), \text{ and} \\ P_A(\text{Unknown} | tH) > P_A(\text{Hostile} | tH).$$

If this situation were to be reversed (i.e. if the values for  $P_A(\text{Unknown}|\text{tF})$  and  $P_A(\text{Hostile}|\text{tF})$  were switched as well as  $P_A(\text{Unknown}|\text{tH})$  and  $P_A(\text{Hostile}|\text{tH})$ ) the declaration ordering would revert to that for Profiles 1-4 in the previous section.

The previous example suggests a better measure of a sensor's accuracy than the profile determinant should be obtained. A new measure will be introduced in the next section.

Another profile of interest is given in Table 12. For Profile 6, Sensor A is clearly less accurate than Sensor B, as is the case for Profiles 1-4, although the declaration ordering set out in Table 13 is not the same.

Table 12 Sensor combination Profile 6

Profile 6	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.75	0.15	0.1
	tH	0.15	0.75	0.1
		F-B	H-B	U-B
Sensor B	tF	0.88	0.03	0.09
	tH	0.03	0.88	0.09

Table 13 Declaration ordering for Profile 6

Increasing aggression factor →									
Output vectors	e	h	b	f	i	c	d	g	a
Sensor outputs	A-H B-H	A-U B-H	A-F B-H	A-H B-U	A-U B-U	A-F B-U	A-H B-F	A-U B-F	A-F B-F

The above ordering seems intuitively obvious; sensor B (the more accurate) is "believed" first and then sensor A is used as a double check.

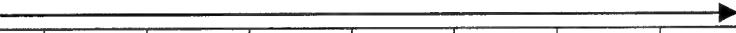
If the profiles of the individual sensors in Profile 6 were to be switched to give Profile 6' in Table 14, then in this case Sensor A would be more accurate than Sensor B.

Table 14 Sensor combination Profile 6'

Profile 6'	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.88	0.03	0.09
	tH	0.03	0.88	0.09
		F-B	H-B	U-B
Sensor B	tF	0.75	0.15	0.1
	tH	0.15	0.75	0.1

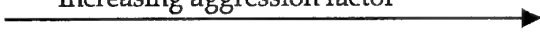
A different declaration ordering given in Table 15 would be obtained.

Table 15 Declaration ordering for Profile 6'

Increasing aggression factor 									
Output vectors	e	f	d	h	i	g	b	c	a
Sensor outputs	A-H B-H	A-H B-U	A-H B-F	A-U B-H	A-U B-U	A-U B-F	A-F B-H	A-F B-U	A-F B-F

The four possible declaration orderings for symmetric sensor profiles are summarised in the following table.

Table 16 The four possible declaration orderings for combinations of two sensors with symmetric profiles

Increasing aggression factor 									
Type 1	e	h	f	b	i	d	c	g	a
	A-H B-H	A-U B-H	A-H B-U	A-F B-H	A-U B-U	A-H B-F	A-F B-U	A-U B-F	A-F B-F
Type 2	e	f	h	d	i	b	g	c	a
	A-H B-H	A-H B-U	A-U B-H	A-H B-F	A-U B-U	A-F B-H	A-U B-F	A-F B-U	A-F B-F
Type 3	e	h	b	f	i	c	d	g	a
	A-H B-H	A-U B-H	A-F B-H	A-H B-U	A-U B-U	A-F B-U	A-H B-F	A-U B-F	A-F B-F
Type 4	e	f	d	h	i	g	b	c	a
	A-H B-H	A-H B-U	A-H B-F	A-U B-H	A-U B-U	A-U B-F	A-F B-H	A-F B-U	A-F B-F

It is possible to construct symmetric sensor profiles of all four types.

Remember the declaration orderings are just rankings of the ratios

$$\frac{P(\mathbf{x}|tH)}{P(\mathbf{x}|tF)}$$

for  $\mathbf{x} \in \{\mathbf{a}, \mathbf{b}, \mathbf{c}, \dots, \mathbf{i}\}$ . It has always been assumed that  $P_*(F|tF)$  and  $P_*(H|tH)$  are at least 0.7 for each sensor, hence  $\frac{P_*(H|tH)}{P_*(H|tF)} > 1$ . For symmetric sensor profiles

$\frac{P_*(U|tH)}{P_*(U|tF)} = 1$ , so it is easy to determine how the various profile entries effect the type of declaration ordering.

$$\text{Type 1 } \frac{P_A^2(H|tH)}{P_A^2(H|tF)} > \frac{P_B(H|tH)}{P_B(H|tF)} > \frac{P_A(H|tH)}{P_A(H|tF)}$$

$$\text{Type 2 } \frac{P_B^2(H|tH)}{P_B^2(H|tF)} > \frac{P_A(H|tH)}{P_A(H|tF)} > \frac{P_B(H|tH)}{P_B(H|tF)}$$

$$\text{Type 3 } \frac{P_B(H|tH)}{P_B(H|tF)} > \frac{P_A^2(H|tH)}{P_A^2(H|tF)}$$

$$\text{Type 4 } \frac{P_A(H|tH)}{P_A(H|tF)} > \frac{P_B^2(H|tH)}{P_B^2(H|tF)}$$

## 4. Asymmetric Sensor Profiles

Previously only symmetric sensor profiles have been investigated. In this section asymmetric profiles will be examined. For example, Profile 7 given in Table 17 is obviously asymmetric.

Table 17 Sensor combination Profile 7

Profile 7	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.75	0.15	0.1
	tH	0.08	0.91	0.01
		F-B	H-B	U-B
Sensor B	tF	0.91	0.03	0.02
	tH	0.07	0.9	0.03

The declaration ordering for this profile is given in Table 18.

Table 18 Declaration ordering for Sensor Profile 7

Increasing aggression factor →									
Output vectors	e	f	b	h	d	c	i	a	g
Sensor outputs	A-H B-H	A-H B-U	A-F B-H	A-U B-H	A-H B-F	A-F B-U	A-U B-U	A-F B-F	A-U B-F

It is interesting to note that for this profile the last sensor output vector to be included in the declaration rule is **g** rather than **a**. This is because the declaration ordering is determined by the ranking of the values  $\frac{P(\mathbf{x}|tH)}{P(\mathbf{x}|tF)}$  and for vectors **a** and **g**,

$$\frac{P(\mathbf{a}|tH)}{P(\mathbf{a}|tF)} = \frac{P_A(F|tH)P_B(F|tH)}{P_A(F|tF)P_B(F|tF)} \geq \frac{P(\mathbf{g}|tH)}{P(\mathbf{g}|tF)} = \frac{P_A(U|tH)P_B(F|tH)}{P_A(U|tF)P_B(F|tF)}.$$

If asymmetric sensor profiles are examined, then the method by which the accuracy of a sensor is measured takes on more importance. It has been shown using Profile 5 that the profile determinant defined in Section 3 will not always give us the same accuracy ranking as obtained through analysis of the Haspert model. Consider these further examples.

Table 19 Sensor combination Profile 8

Profile 8	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.8	0.12	0.08
	tH	0.15	0.8	0.05
Sensor B	tF	0.95	0.03	0.02
	tH	0.03	0.93	0.04

Table 20 Sensor combination Profile 9

Profile 9	Assumed target	Sensor output probabilities		
		F-A	H-A	U-A
Sensor A	tF	0.8	0.15	0.05
	tH	0.12	0.8	0.08
Sensor B	tF	0.95	0.03	0.02
	tH	0.03	0.93	0.04

Now Profiles 8 and 9 have the same declaration ordering (e, h, f, b, i, c, d, g, a) and in both cases Sensor A has a determinant of 1.33. However, for an aggression factor of 0.2, using Profile 8 the vectors e, h, f and b will be included in the hostile declaration rule, while using Profile 9 only e, h, and f would be included. Further, for an aggression factor of 20 Profile 9 will have 8 output vectors in its declaration rule, while Profile 8 will only have 7. These two facts combined suggest that Profile 8 is more accurate than Profile 9, even though they have the same profile determinant. The difference between these profiles lies in the terms  $P_A(H | tF)$  and  $P_A(F | tH)$ . If the former term is large, this will be more detrimental to the accuracy (as reflected by the Haspert model) than if  $P_A(F | tH)$  is large. This might suggest that a better sensor determinant definition for the purposes of making hostile declarations would be

$$\frac{P_*(H | tH)}{P_*(H | tF)}.$$

If this was used as the determinant for an individual sensor, and the profile determinant was defined as the sum of the individual sensor determinants, the same accuracy ranking for Profiles 1-4 would be obtained as that established in Section 2.

The main objective of the Haspert model is to successfully identify hostile combatants. However, if the task at hand was to identify friendly targets then an appropriate sensor determinant might be

$$\frac{P_*(F | tF)}{P_*(F | tH)}.$$

## 5. Non-independent Profiles

Statistical dependence of sensor profiles can be accommodated in the Haspert model if for a given sensor combination a joint profile such as that given in Table 21 can be constructed.

Table 21 A joint sensor profile for two sensors with correlated output

	Sensor output vectors								
	a	b	c	d	e	f	g	h	i
Actual target type	F-A	F-A	F-A	H-A	H-A	H-A	U-A	U-A	U-A
	F-B	H-B	U-B	F-B	H-B	U-B	F-B	H-B	U-B
tF	0.75	0.05	0.05	0.01	0.01	0.02	0.06	0.02	0.03
tH	0.01	0.05	0.01	0.03	0.8	0.02	0.05	0.01	0.02

This joint profile could be obtained either experimentally, or by combining the individual sensor profiles using information on the correlation of the sensor outputs. Once the joint profile is obtained, determining the sensor output vectors to be included in the hostile declaration rule can be achieved by comparing the ratios  $\frac{P(\mathbf{x} | tH)}{P(\mathbf{x} | tF)}$  to the aggression factor.

## 6. Three Target Type Problem

Previously, the Haspert model has been examined when the only target types under consideration are friendly and hostile combatants. In this section, the results of implementing the model in a situation where neutral targets are involved will be investigated.

It will be necessary to examine sensor profiles of the form given in Table 22.

Table 22 An individual sensor profile for the three target type problem

	Sensor Output			
Actual target type	F	H	N	U
tF	$P_*(F   tF)$	$P_*(H   tF)$	$P_*(N   tF)$	$P_*(U   tF)$
tH	$P_*(F   tH)$	$P_*(H   tH)$	$P_*(N   tH)$	$P_*(U   tH)$
tN	$P_*(F   tN)$	$P_*(H   tN)$	$P_*(N   tN)$	$P_*(U   tN)$

Of course, in the case of neutral parties it would be desirable to know if the sensors were actually detecting them as neutrals or simply as "unknown". This distinction could make a significant difference in the assessment of the model.

Haspert assigns a cost to the misidentification of hostiles, friendly and neutral targets. The total cost function in this case is

$$C_T = C_{pL} \times N_H \times p(\text{hostile not declared hostile}) + C_F \times N_F \times p(\text{friend declared hostile}) \\ + C_N \times N_N \times p(\text{neutral declared hostile}).$$

Here  $C_N$  is the cost assigned to each misidentification of a neutral as a hostile and  $N_N$  is the number of neutrals in the engagement.

If  $(1 - y)$ ,  $x$  and  $z$  are substituted for the probability terms in the total cost expression the following equation is obtained:

$$C_T = C_F N_F x + C_{pL} N_H (1 - y) + C_N N_N z.$$

This is the equation of a plane, so again a normal vector will be defined and will be used to determine the set of sensor output vectors to be included in the hostile declaration rule.

This time however, it will not be possible to define a single number to express the relationship of the various cost parameters. Instead of using a single aggression factor, a vector will need to be defined.

$$V = \begin{pmatrix} C_F N_F \\ -C_{pL} N_H \\ C_N N_N \end{pmatrix}$$

At a minimum two numbers need to be chosen to give a normal vector for constructing a hostile declaration rule. e.g.

$\frac{C_{pL} N_H}{C_F N_F}$  and  $\frac{C_N N_N}{C_F N_F}$ . The first of these ratios will be called the Friendly-Hostile (FH) aggression factor, and the second the Friendly-Neutral (FN) aggression factor. The FN aggression factor could vary significantly depending on the number and type of the neutral parties being considered. The misidentification of an individual neutral civilian as a hostile would normally be regarded as less costly than the potential fratricide of a friendly combatant. In such cases  $C_N / C_F$  would be set at a value less than one. By contrast, in a littoral combat near a civilian airport in which the friendly combat units were small fighter aircraft and the expected neutrals were large airliners, then the ratio  $C_N / C_F$  could be set at a value much greater than one.

Given two sensors with four possible output indications (Friendly, Hostile, Neutral and Unknown) there are  $16=4^2$  possible sensor output vectors (**a**, **b**, **c**, ..., **m**, **n**, **o**, **p**).

For a given FN factor there will a declaration ordering which lists the sensor output vectors included in the hostile declaration rule as the FH factor increases. For example consider the sensor profiles given in Table 23.

Table 23 Sensor combination Profile 10

Profile 10	Assumed target	Sensor output probabilities			
		F-A	H-A	N-A	U-A
Sensor A	tF	0.8	0.1	0.05	0.05
	tH	0.1	0.8	0.05	0.05
	tN	0.02	0.02	0.7	0.26
		F-B	H-B	N-B	U-B
Sensor B	tF	0.95	0.03	0.01	0.01
	tH	0.03	0.95	0.01	0.01
	tN	0.05	0.1	0.72	0.13

For different FN factors there will be different declaration orderings as the FH factor increases. This is due to the fact that in the three target type problem the declaration orderings for a fixed FN factor (denoted  $A_{FN}$ ) are determined by the ranking of the ratios

$$\frac{P(\mathbf{x} | tH)}{P(\mathbf{x} | tF) + A_{FN} \cdot P(\mathbf{x} | tN)}$$

For example for an FN factor of 0.1, the following declaration ordering results:

Table 24 Declaration ordering for Profile 10 at  $A_{FN}=0.1$ 

Increasing FH aggression factor →															
f	n	h	j	b	g	e	p	d	c	l	m	i	o	k	a
A-H	A-U	A-H	A-N	A-F	A-H	A-H	A-U	A-F	A-F	A-N	A-U	A-N	A-U	A-N	A-F
B-H	B-H	B-U	B-H	B-H	B-N	B-F	B-U	B-U	B-N	B-U	B-F	B-F	B-N	B-N	B-F

For an FN factor of 0.2 a different declaration ordering is obtained:

Table 25 Declaration ordering for Profile 10 at  $A_{FN}=0.2$ 

Increasing FH aggression factor →															
f	n	h	b	j	g	e	d	c	p	m	i	l	o	k	a
A-H	A-U	A-H	A-F	A-N	A-H	A-H	A-F	A-F	A-U	A-U	A-N	A-N	A-U	A-N	A-F
B-H	B-H	B-U	B-H	B-H	B-N	B-F	B-U	B-N	B-U	B-F	B-F	B-U	B-N	B-N	B-F

Now for the ordering given in Table 25 it should be noted that the sensor output vector **b** will be included in the hostile declaration rule before vector **j**. So supposing that Sensor B indicated a hostile combatant, the target would be more likely to be engaged if sensor A indicated a friend than if it indicated a neutral. This would seem to be a very counter-intuitive strategy.

A more intuitive declaration ordering might satisfy the following restrictions.

- (1)  $f \triangleleft j \triangleleft b$ ;
- (2)  $h \triangleleft l \triangleleft d$ ;
- (3)  $g \triangleleft k \triangleleft c$ ;
- (4)  $e \triangleleft i \triangleleft a$

Here  $x \triangleleft y$  signifies that  $x$  will be included in the hostile declaration rule at a lower FH aggression factor than  $y$ . Each of these conditions would fix the output of sensor B, while the output of sensor A would be in order: Hostile, Neutral, Friendly. Using Profile 10 with an FH factor of one, it would be necessary to reduce the FN factor to approximately 0.005 to obtain a declaration ordering which satisfied these four conditions. In an engagement with an equal number of Friendly, Hostile and Neutral combatants, this would equate to setting the cost of a friendly kill at 200 times that of a neutral kill.

While the variation in the declaration orderings makes comparison of hostile identification rules at different FN factors difficult, the following graph represents declaration profiles at different FN factors.

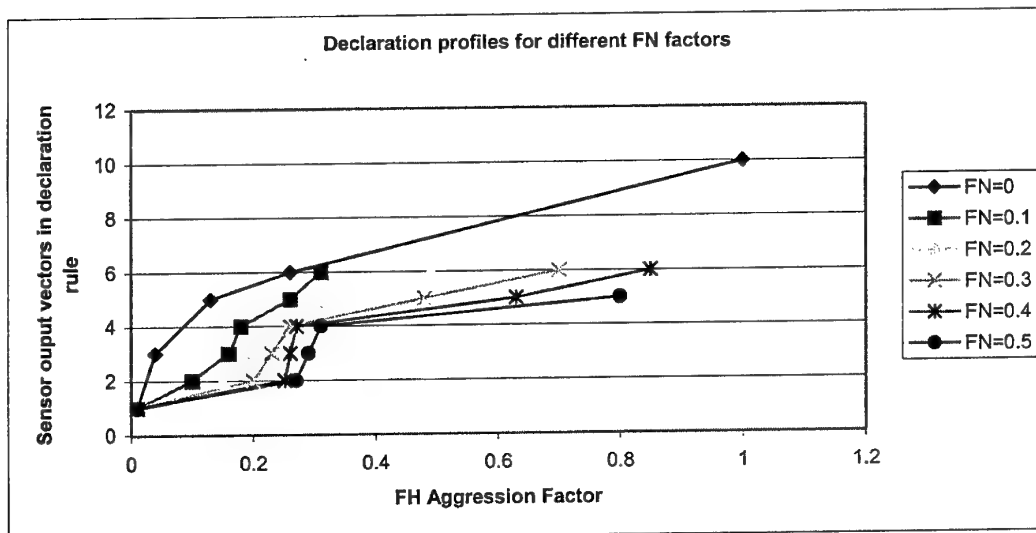


Figure 4 No of sensor output vectors in hostile identification rule for Profile 10 at different FN factors

Figure 4 shows that the higher the FN factor, the fewer sensor output vectors are included in the hostile declaration rule for a given FH factor. This is as would be expected, as an increased FN factor will indicate that greater care should be taken in

making hostile declarations. While this graph only includes FH Aggression factors up to a value of 1, the same behaviour can be demonstrated for higher FH factors

It is not easy to compare sensor combinations of different accuracy in a three-combatant type problem. Note the following comparison of Profiles 10 and 11. Profile 11 is given in Table 26.

Table 26 Sensor combination Profile 11

Profile 11	Assumed target	Sensor output probabilities			
		F-A	H-A	N-A	U-A
Sensor A	tF	0.79	0.11	0.05	0.05
	tH	0.11	0.79	0.05	0.05
	tN	0.02	0.02	0.7	0.24
Sensor B	tF	0.95	0.03	0.01	0.01
	tH	0.03	0.95	0.01	0.01
	tN	0.05	0.1	0.72	0.13

Profile 11 is slightly less accurate than Profile 10. Both have the same declaration ordering (see above). In the following table the FN factor is set a 0.1 for both profiles.

Table 27 Minimum FH aggression factors for each number of sensor output vectors in hostile declaration rule for Profile 10 and 11 with  $A_{FN}=0.1$

No of sensor output vectors in declaration rule	Approximate minimum FH aggression factor for no of vectors	
	Profile 10	Profile 11
1	0.01	0.01
2	0.1	0.1
3	0.16	0.173
4	0.179	0.179
5	0.26	0.23
6	0.31	0.33
7	4.0	4.5
8	7.3	7.3
9	8.3	7.5
10	9.5	8.5

Now for a fixed FN factor, a declaration profile comparison similar to Figure 3 might be expected. However from the above table it can be seen that this is not the case. The

graphs of the sensor profiles would cross more than once as the FH aggression factor increases. In Figure 5 below the  $x$ -axis scale has been adjusted to emphasise this fact.

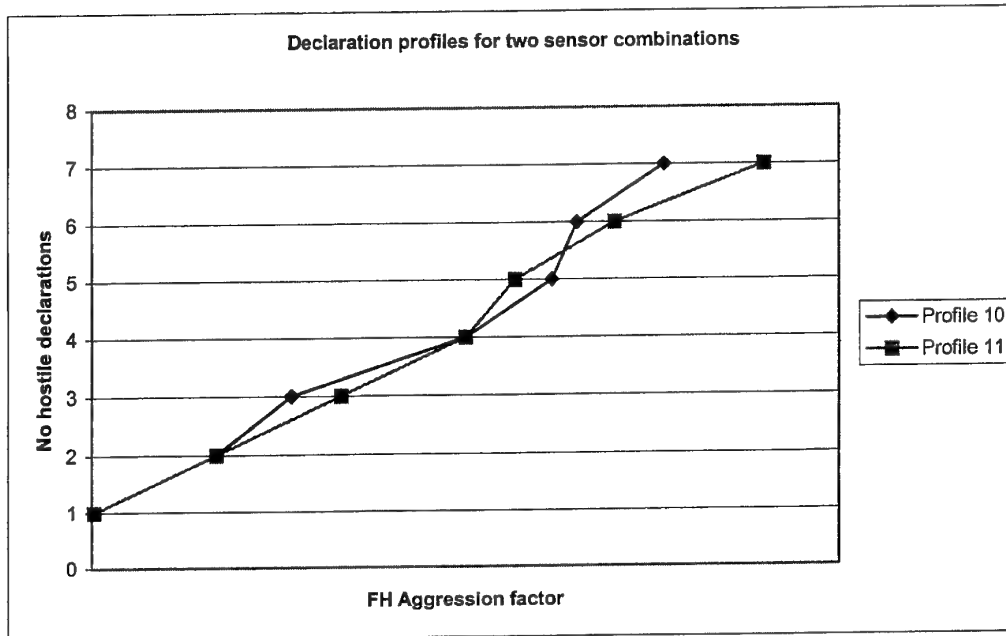


Figure 5 Comparison of hostile identification rules for Profiles 10 and 11. ( $x$ -axis not to scale)

## 7. Discussion and Implementation Issues

The Haspert model was devised with the aim of broadening the theory of target identification to include the possibility of neutral parties in a military engagement. However in order for the model to work it is assumed that combatants have as much information about neutral parties (how many there are, what their sensor response would be etc) as they would have about hostile combatants. The real challenge of littoral engagements, for example, is that combatants can often be presented with a wide range of neutral targets of often unexpected nature. It would probably be appropriate in such circumstances to use visual, or some other, confirmation combined with sensor output in making hostile identifications.

One of the major issues with the Haspert model is the choice of the cost parameters  $C_{pL}$ ,  $C_F$  and  $C_N$ . As the choice of these parameters can significantly affect the sensor output vectors which would result in a hostile identification it might be desirable to set some kind of limits on the range of choices possible. These ranges may be somewhat

dependent on the accuracy of the sensor equipment employed, as well as the likely engagement scenarios being considered.

Along with the possible range of cost parameters, in certain engagements it might be difficult for commanders to select cost parameters without the knowledge of the numbers of combatants involved detrimentally affecting their choice. For example, if allied forces heavily outnumber hostile combatants in a two target type engagement then  $C_F$  may be set unnecessarily low in relation to  $C_{pL}$ . This may result in a level of fratricide higher than would ordinarily be expected in achieving a given military objective.

The ratio  $C_{pI}/C_F$  is meant to reflect the relative cost of not identifying an individual hostile combatant compared to the cost of an individual fratricide and should not be confused with other parameters which military commanders may be more familiar with.

Very little concrete evaluation of the Haspert approach can be made without reference to the entire combat scenario under consideration. While the model may provide a suitable strategy for identification of *potential* hostile targets, it gives no guidance on the engagement priority for these targets or ID confirmation. Presumably a natural priority ranking for targets could be given by the declaration orderings, with some adjustments made for target proximity and other relevant factors.

Given a set of potential hostile targets for selected cost parameters it might be expected that ID confirmation measures would increase on engaging targets with sensor output vectors further down the declaration ordering. For example, in the two target type problem vector **e** (Sensors A & B both identify as hostile) has always been at the head of the declaration ordering. Presumably a target with this sensor output vector would be given high priority in an engagement sequence with only minimal measures taken to confirm identity. A target with sensor output vector **d** on the other hand (Sensor A – hostile Sensor B –friendly) would have a lower engagement priority and would require more substantial ID verification measures prior to further progression down the engagement path.

Ultimately, the ability to correctly identifying hostile combatants depends upon the accuracy of the sensors used. The Haspert model assumes that the sensor profiles will remain fixed in any given environment. While there may be many engagement scenarios where such an assumption is appropriate, there are clearly exceptions. In a littoral environment, for example, radar identifications of air combatants over land may be less accurate than those made for combatants over open ocean.

## 8. Conclusion

The main benefit which might be achieved through implementation of the Haspert model, would be a greater degree of flexibility in determining rules for target declaration. Using a total cost approach, the model takes into account the number of hostile, neutral and friendly combatants, as well as sensor reliability in any given combat environment.

However, to use the Haspert model at least one cost parameter must be set for each engagement. The choice of cost parameters could be highly variable, if left to individual commanders. In many military conflicts there would not always be sufficient time for a commander to make an intelligent and informed choice.

In addition, some of the results from the model would suggest that in many instances declaration rules would be determined which would conflict with the intuitive judgement of military commanders. In such circumstances, the target identifications would probably be disregarded by commanders.

The model can accommodate neutral parties in the target declaration problem, although in practice such an approach might be of limited benefit as the nature and number of neutral parties would have to be known beforehand.

## 9. References

- 1 J.Kent Haspert, *Optimum ID Sensor Fusion for Multiple Target Types*, Institute for Defense Analyses, Document D-2451, March 2000.
- 2 James M. Ralston, *Bayesian Sensor Fusion for Minimum-Cost ID Declarations*, 1998 Joint Service Combat Identification Systems Conference on Requirements, Technologies and Developments (CISC-98), Vol 1 -Technical Proceedings.

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19. ABSTRACT The Haspert model for target identification using multiple sensors is examined. Haspert takes a total-cost approach in constructing identification rules for engagements in which friendly, hostile and neutral parties are involved. While the model has certain advantages in terms of command and scenario flexibility, the resulting identification rules vary considerably according to the cost parameters set by commanders, and in some cases are counterintuitive. The model does not offer significant advantages in the identification of neutrals unless information on the nature and number of these parties is available prior to the engagement.									